Educational methodologies based on Maturana and Varela's theory of knowledge for teaching natural sciences

Metodologías educativas desde la teoría del conocimiento de Maturana y Varela para enseñanza de las ciencias naturales

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Abstract

The study arises in response to the low performance and lack of interest of students in physics, chemistry and biology. Observing that natural science teachers focus on rigid and traditional methodologies, disconnected from the reality of the students. The objective was to analyze the possibilities offered by Maturana and Varela's theory of knowledge for the development of educational methodologies in the teaching of natural sciences. The socio-critical paradigm and participatory action research were used, with diagnosis, planning, implementation and evaluation phases, carried out with 5th year students in the three subjects, collecting data from 12 teachers and students. The study concludes that the methodology based on the theory of knowledge positively impacts the performance and motivation of students. The information obtained guides transformations in educational practices, revitalizing the teaching of natural sciences and strengthening student commitment in these disciplines.

Palabras claves: Tools, Moodle Platform, Teacher Challenges and technologies.

Resumen

El estudio surge como respuesta al bajo rendimiento y falta de interés de los estudiantes en física, química y biología. Observándose que los docentes de ciencias naturales se centran en metodologías rígidas y tradicionales, desvinculadas de la realidad de los estudiantes. El objetivo fue analizar las posibilidades que ofrece la teoría del conocimiento de Maturana y Varela para el desarrollo de metodologías educativas en la enseñanza de las ciencias naturales. Se empleó el paradigma socio-crítico y la investigación acción participativa, con fases de diagnóstico, planificación, implementación y evaluación, ejecutándose con estudiantes de 5to año en las tres asignaturas, recopilando datos de 12 docentes y estudiantes. El estudio concluye que la metodología basada en la teoría del conocimiento impacta positivamente el rendimiento y la motivación de los estudiantes. La información obtenida orienta transformaciones en prácticas educativas, revitalizando la enseñanza de ciencias naturales y fortaleciendo el compromiso estudiantil en estas disciplinas.

Palabras clave: metodologías educativas, teoría del conocimiento, ciencias naturales.

Introduction

Throughout history, mankind has persisted in a constant quest for knowledge, and ancient literature, such as the Bible, offers a fascinating perspective on humanity's early attempts to understand the world around them. The Reina Valera (1960) version of the book of Genesis 3 provides an illustrative example of this ancient inquiry.

> 4 And the serpent said to the woman, "You will not surely die. 5 For God knows that in the day you eat of it your eyes will be opened, and you will be like God, knowing good and evil." 6 So when the woman saw that the tree was good for food, that it was pleasant to the eyes, and a tree desirable to make one wise, she took of its fruit and ate. She also gave to her husband with her, and he ate.

Synthesizing the previous ideas, it can be observed that, in the verses of Genesis, it explores how the first human beings faced the temptation to acquire knowledge, symbolized by the act of eating from the tree of the knowledge of good and evil. This narrative not only sheds light on the origins of human knowledge-seeking but also raises fundamental questions about the relationship between the pursuit of knowledge and ethics.

Thus, by examining the roots of this concern in ancient literature, a window is opened to understanding the human motivations behind the quest for knowledge throughout time. From an educational perspective, the Genesis narrative highlights the importance of seeking a balanced knowledge that is intimately linked to ethics. The serpent's promise that, by eating from the tree of knowledge, humanity would attain wisdom and be "like God, knowing good and evil," suggests the intrinsic connection between knowledge and the ability to discern between right and wrong.

From the standpoint of the author of this work in the educational field, this story can be interpreted as a reminder of the need for a balanced approach in the acquisition of knowledge. It is not simply about seeking knowledge for its own sake but understanding how that knowledge relates to ethics and morality. The emphasis is on cultivating an ethical awareness alongside the pursuit of knowledge.

While from a philosophical perspective, it suggests that effective education is not just about accumulating information but also about fostering the ability to discern and apply that knowledge ethically. Educators have a responsibility to guide students toward a comprehensive understanding that enriches not only their minds but also develops their ethical discernment.

In this line of thought and trying to contextualize the central theme of this study, a summary is made from the perspective of the researcher to the book "The Tree of Knowledge: The Biological Roots of Human Understanding" by Humberto Maturana and Francisco Varela. It is inferred that this text stands out as a fundamental work in the biology of knowledge. The authors propose an innovative theory that challenges the traditional notion that knowledge is a direct copy of reality. Instead, they argue that knowledge is an emergent construction of the continuous interaction between an organism and its environment, where cognitive structures are generated through biological processes (Maturana & Varela, 1990).

Likewise, Jové (2022) considers that this approach has significantly impacted the understanding of knowledge and has permeated various fields of knowledge. Particularly in understanding the notion of this work "the tree of knowledge," it can influence education by altering the perspective on learning, as Maturana and Varela's proposed theory suggests that learning is not simply the accumulation of information but an active process of knowledge construction.

Therefore, Parada (2023) considers that this paradigm shift has stimulated new educational methodologies, emphasizing active student participation, collaborative knowledge construction, and reflection on educational practice. Furthermore, this text allows the author of this study to deduce that this book represents a contribution to improving the quality of education by inspiring educational policies that seek to raise standards. Hence, the researcher considers that this book can contribute to the understanding of learning as knowledge construction and drive changes in how educational policies are approached, promoting more dynamic and participatory

According to Ortiz (2015), in the educational context, this implies recognizing and fostering students' ability to generate their own understandings, rather than simply receiving information passively. According to Obando & Galviz (2023), these methodologies should aim to create environments where students can identify themselves and others, thus promoting a deeper understanding of themselves and the world around them.

In the view of Rodríguez & Torres (2003), educational processes in the classroom should be directed towards the collaborative construction of knowledge, fostering interaction and dialogue among students. The emphasis on reflection on educational practice suggests that educators should be facilitators who guide and support the learning process, rather than mere transmitters of information.

Considering the ideas of the aforementioned authors, the researcher believes that an approach of innovative educational methodologies from the theory of knowledge of Maturana and Varela drives a profound change in how we conceive teaching and learning. It is about empowering students as active constructors of their knowledge, promoting recognition, collaboration, and reflection in a dynamic and participatory educational environment.

In this line of thought, Ruiz & Abad (2019) consider that innovative educational methodologies play a fundamental role in improving and adapting the educational process. Their importance lies in their ability to respond to the individual needs of students, offering a personalized approach that recognizes diversity in learning styles.

According to De La Aldea (2019), by stimulating critical thinking, these methodologies go beyond memorization, promoting deep understanding and active application of knowledge. Furthermore, they cultivate creativity by challenging students to approach problems from various perspectives, fostering original solutions and preparing them to face real-world challenges.

For Arnold *et al.* (2011), an important aspect of these methodologies is their emphasis on collaborative learning, reflecting the importance of teamwork and communication skills in social and work environments, as integrating practical and contextualized approaches prepares students to apply their knowledge effectively. Likewise, motivation and engagement are increased through dynamic and engaging approaches, using educational technology and promoting active participation.

Finally, Correa-Díaz *et al.* (2019) point out that the constant updating of these methodologies contributes to keeping education relevant and equips students with relevant skills in an ever-evolving environment. Together, innovative educational methodologies are essential for providing comprehensive education and preparing students for success in contemporary society.

Therefore, di Pasquo *et al.* (2020) highlight that the application of educational methodologies from the perspective of Maturana and Varela's theory of knowledge for teaching natural sciences represents an innovative and transformative approach in the educational field since this theory, known as the biology of knowledge, contends that knowledge is not a direct copy of reality but an active construction that arises from the interaction between the organism and its environment.

According to Méndez (2018) and Mendoza & Godoy (2016), based on this foundation, educational methodologies focus on promoting students' active participation in constructing their own knowledge. Significant learning is promoted, where students not only absorb information but also engage in practical experiences that allow them to build their understanding of natural sciences. Additionally, Toro & Vega (2021) argue that applying this theory in teaching natural sciences involves designing activities and resources that stimulate curiosity, exploration, and questioning. The aim is to create an educational environment that reflects the complexity and interconnectedness of natural phenomena, enabling students to develop a deep and contextualized understanding.

In the view of Jové (2022), it is important that educational processes in biology align with the principles of Maturana and Varela's theory of knowledge, as these authors propose adaptability and flexibility in the application of these methodologies, thus allowing for a dynamic response to the specific needs and characteristics of students, promoting active and meaningful learning in the fascinating world of natural sciences.

Considering the aforementioned approaches, this study focused on analyzing the possibilities offered by Maturana and Varela's theory of knowledge for the development of educational methodologies in teaching natural sciences.

Metodology

The study aims to improve the processes of teaching natural sciences, so it was proposed to analyze the possibilities offered by Maturana and Varela's theory of knowledge for the development of educational methodologies in the teaching of natural sciences. It should be noted that the study initially targeted 12 teachers from the natural sciences area as they are responsible for the teaching processes. They were presented with the action plan to implement it in their physics, chemistry, and biology classes, selecting a section of 36 students from three sections A, B, and C of the José Antonio Almarza Educational Unit in the Zulia state, Mara municipality. In this regard, the initial step was the teaching action aimed at consolidating the understanding of texts according to the interests and needs of the learner.

In reference to this, an action plan was designed that started from a diagnosis, which was carried out to obtain information about the real needs in the teaching of natural sciences. Therefore, it was necessary to gather information in its real context. In this sense, it worked through the feasible project modality, so an operational model was developed to provide a solution to the problem studied (Hurtado, 2015).

Hence, the procedures of the Participatory Action Research (PAR) method were adopted, which is defined by Rojas (2002) as a methodological approach that combines social research with social action. It is an iterative process in which researchers and participants work together to identify and solve social problems. Similarly, for Flores (2021), it is a methodological approach that integrates research and action with active participation of those involved in the process. According to Ansoleaga (2019), it focuses on addressing specific problems in practical contexts through collaboration between researchers and community members.

According to Scribano (2007), this research method (PAR) is linked to field design, which was developed systematically and orderly, through several phases that contributed to achieving the proposed objectives. In this regard, in the context of analyzing the potential applications of Maturana and Varela's theory of knowledge in the design of educational methodologies for teaching natural sciences, Participatory Action Research (PAR) is deployed according to Ansoleaga's (2019) criterion as follows:

In the diagnosis stage, researchers and participants collaborated to identify difficulties in learning natural sciences through observation methods and interviews. This phase included reflection, that is, jointly analyzing the results of the diagnosis. Through the planning stage, they worked together to develop an action plan aimed at addressing the identified problems. This plan incorporated new educational strategies aligned with Maturana and Varela's theory of knowledge.

Likewise, the execution of the plan was considered, which was carried out in stages, where researchers and participants would collaborate in the design and implementation of specific educational activities. Finally, the evaluation phase, which involved reviewing and analyzing the results of the action plan, using observation methods and interviews. This allowed analyzing changes in student learning through discussion groups or workshops, thus closing the PAR cycle. Therefore, it is important to note that the effectiveness in teaching natural sciences will be evaluated through the performance of the students, so the diagnosis starts from their reality.

Table 1
Initial teacher diagnosis of the situation in light of the thematic concern

Diagnosis of the teaching-learning process in natural sciences among fifth-year students at José Antonio Almarza High School.	
Objective	Identifying the possible causes of the lack of effectiveness in the teaching strategies of natural science teachers.
Methods	Gathering information on the following aspects: • Learning objectives. • Teaching strategies. • Student participation. • Student attitudes.
Guiding Questions	• What are the learning objectives that natural science teachers are trying to achieve? • Are these objectives clear and measurable? • What teaching strategies are natural science teachers using? • Are these strategies suitable for the learning objectives? • How are students participating in the classes? • Are students engaged in learning activities? • What are the attitudes of students towards natural sciences? • Are students motivated to learn natural sciences?

Results	• Learning objectives may be too vague or difficult to achieve. • Teaching strategies are not suitable for the learning objectives. • Learning activities are not engaging or challenging for the students. • The teachers are unable to motivate students or create a positive learning environment.
Conclusions	It is necessary to examine the learning goals to ensure their clarity and measurability. Appropriate pedagogical tactics should be chosen in line with these objectives. Likewise, educational activities that are engaging and challenging for students need to be conceived. Additionally, it is imperative to cultivate motivation skills and foster the creation of a positive learning environment.

Note: Own elaboration (2024).

Natural science educators exhibited deficiencies that impacted the effectiveness of their teaching methods. Among the fundamental causes, the lack of precision in learning objectives stands out. The clarity and measurability of these objectives are essential for planning suitable teaching strategies. If the objectives are ambiguous or difficult to achieve, it is likely that the strategies will be ineffective.

Likewise, another determining factor that was evidenced was the use of inadequate teaching strategies. These strategies must be properly aligned with the learning objectives to ensure the effectiveness of the process. The inadequacy of the strategies leads to a deficiency in the acquisition of concepts or skills by students.

Additionally, the design of unattractive or unchallenging learning activities also emerges as a prominent cause. These activities must captivate and challenge students to maintain their motivation and commitment to learning. If the activities lack these elements, students are likely not to actively participate in the educational process.

Furthermore, the lack of skills in motivation and creating a positive learning environment by teachers is revealed as a crucial element. Educators must be able to inspire students and foster a positive environment to stimulate the desire to learn. The absence of these skills can result in a lack of motivation on the part of students. It is imperative that natural science teachers recognize these causes and strive to refine their teaching strategies.

Table 2
Diagnosing the students

Diagnosis of the teaching-learning process in natural sciences among fifth-year students at José Antonio Almarza High School.	
Objective	Identifying the difficulties that 5th-year students at José Antonio Almarza High School have in learning natural sciences.
Methods	• Observation: The researchers observed the natural science classes of 5th-year students at José Antonio Almarza High School for one week. • Interviews: The researchers interviewed 10 5th-year students at José Antonio Almarza High School.

Guiding Questions	What are the knowledge and skills that students should acquire in natural science classes? What are the teaching and learning strategies used in natural science classes? What are the attitudes of students towards natural sciences?
Results	• The diagnostic results indicate that 5th-year students at José Antonio Almarza High School struggle to learn natural sciences. These difficulties can be classified into three main categories: • Lack of prior knowledge: Students have difficulties understanding complex scientific concepts because they lack the necessary basic knowledge and skills. For example, students struggle to grasp the concept of evolution because they lack basic knowledge of genetics. • Inadequate teaching strategies: The teaching strategies used in natural science classes are not suitable for the students' needs. For instance, teachers often employ teacher-centered teaching strategies, which limit students' active participation. • Negative attitudes towards natural sciences: Students hold negative attitudes towards natural sciences, which may hinder their learning. For example, students perceive natural sciences as boring or challenging.
Conclusions	• The diagnostic results indicate the need to implement changes in the teaching of natural sciences at José Antonio Almarza High School to address the difficulties students face in learning this content. These changes should focus on the following aspects: • Strengthening students' prior knowledge: Teachers should provide students with the necessary basic knowledge and skills to understand complex scientific concepts. • Using student-centered teaching strategies: Teachers should employ teaching strategies that encourage active student participation. • Fostering positive attitudes towards natural sciences: Teachers should create a positive and stimulating learning environment that motivates students to engage with natural sciences.

Note: Own elaboration (2024).

The results obtained from the diagnosis (which was completed with both a written and oral examination, by subject area) indicate that fifth-year students at José Antonio Almarza High School face significant challenges in learning natural sciences, categorizing these difficulties into three primary categories. Firstly, the lack of prior knowledge is highlighted, revealing that students struggle to comprehend complex scientific concepts due to a lack of fundamental knowledge and skills. An illustrative example is the difficulty in understanding the concept of evolution, attributed to a lack of basic knowledge in genetics. Another relevant aspect is the inadequacy of teaching strategies employed in natural science classes, which fail to meet the specific needs of students. A notable example is the preference for teacher-centered strategies, which limit active student participation in the learning process.

Additionally, the existence of unfavorable attitudes towards natural sciences among students is identified, which may constitute a barrier to their learning process. For instance, the perception that natural sciences are boring or difficult contributes to creating a negative predisposition towards the subject. These findings underscore the need to comprehensively address these issues to improve the quality of learning at José Antonio Almarza High School.

Activity Planning

The results of the diagnosis provided insights into the weaknesses in teaching natural sciences. Based on this information, two action plans were developed: a general one and a specific one.

These plans were designed to be implemented over the course of one school term (3 months), in collaboration with natural science teachers.

Table 3
General Action Plan

Concept	Activity	Objective	Example
Direct observation of autopoietic systems, such as cells or ecosystemss	Understanding how autopoietic systems produce their own conditions of existence.	Autopoiesis In a biology class, students can observe an aquatic ecosystem, such as a pond or a lake. They can record their observations, such as the different types of plants and animals living in the ecosystem, and then analyze their observations to identify the relationships between these organisms.	Understanding the complexity of ecosystems. Developing observation and analysis skills. Promoting environmental awareness.
Analysis of how humans identify themselves and others.	Understanding how recognition influences the construction of knowledge.	Recognition In a history class, students can analyze how scientists from different cultures have developed various theories about the universe. They can discuss how these theories have been influenced by the beliefs and values of different cultures.	Understanding the importance of cultural context in the construction of scientific knowledge. Developing critical analysis skills. Fostering respect for cultural diversity.
Exploration of how humans construct cognitive structures to interpret and understand the world.	Understanding how cognitive structures influence the construction of knowledge..	Cognitive structures In a physics class, students can discuss how scientific theories evolve as new information emerges. They can analyze how new theories build upon existing ones but also introduce new concepts and ways of thinking.	Understanding the dynamic nature of scientific knowledge. Developing critical thinking skills. Fostering scientific curiosity.
Analysis of how knowledge is constructed from experience.	Understanding how knowledge is always contextual and relative.	Knowledge In a social sciences class, students can analyze how different cultures have developed diverse knowledge about nature. They can discuss how this knowledge has been based on the experiences of different cultures with the natural world.	Understanding the dynamic nature of scientific knowledge. Developing critical thinking skills. Fostering scientific curiosity.

Note: Own elaboration (2024).

These activities were tailored to the educational level of fifth-year high school students and various topics in the natural sciences. Their aim was to promote active student participation in the learning process, collaborative knowledge construction, and reflection on educational practice.

In this regard, in the physics class, students were invited to observe a pendulum in motion. They recorded data on the pendulum's movement and then analyzed it to identify the laws governing its motion. This activity also promoted active student participation in the learning process, as students collected their own data and analyzed it. At the same time, they compared observations and conclusions with their peers.

Meanwhile, in the biology class, students were invited to work in groups to conduct research on a coral reef ecosystem. They collected information on the different components of the ecosystem and then analyzed it to identify the relationships between these components. This activity promotes active student participation in the learning process, as students must research and analyze information. Additionally, it fosters collaborative knowledge construction, as students must work together to collect and analyze information.

Similarly, in the chemistry class, students were invited to conduct an experiment to investigate the behavior of a chemical substance. They recorded data from the experiment and then analyzed it to identify the properties of the chemical substance. This activity promotes active student participation in the learning process, as students must design and conduct the experiment. Additionally, it fosters collaborative knowledge construction, as students can share their observations and conclusions with their peers.

Based on the above, a series of activities were proposed as part of the action plan to be implemented with fifth-year students.

Table 3

General Action Plan

Area	Activities	Objective	Materials	Procedures
Biology	Research on a biological phenomenon.	Linking Learning to Students' Experiences.	Paper and Pencil for the Students. A Biological Phenomenon to Investigater.	The teacher presents the biological phenomenon to the students. The students present the results of their investigation in class. The students divide into groups to investigate the phenomenon. The students conduct the investigation in the classroom or in the field.
	Design of a Biological Experiment.	Linking Learning to Students' Experiences.	Paper and Pencil for the Students. A Biological Phenomenon to Investigater.	The teacher presents the biological phenomenon to the students. The students present the results of their investigation in class. The students divide into groups to investigate the phenomenon. The students conduct the investigation in the classroom or in the field.

Area	Activities	Objective	Materials	Procedures
Biology	Creation of a Biological Model	Fostering Understanding of Scientific Concepts.	Materials for Creating the Model	The teacher presents a scientific concept to the students. The students divide into groups to create a model of the scientific concept. The students present their models to the rest of the class.
Physics	Reconstruction of a Physical Experiment	Promoting the Understanding of Scientific Concepts.	Materials for Conducting the Experiment	The teacher presents a scientific problem to the students. The students work in groups to design a project to solve the problem. The students carry out the project. The students present the results of their project to the class.
	Design of a Scientific Project	Promote Active Student Participation in the Learning Process	Materials for Conducting the Project	The students work in groups to develop a scientific project. The students present their projects at a science fair.
	Participation in a Science Fair	Linking Learning to Students' Experiences	Materials for the Project	The teacher presents the chemical reaction to the students. The students divide into groups to investigate the reaction. The students conduct the investigation in the classroom or in the laboratory. The students present the results of their investigation to the class.
Chemicalc	Biology	Linking Learning to Students' Experiences	Paper and pencil for the students. A chemical reaction to investigate.	The teacher presents the chemical reaction to the students. The students divide into groups to investigate the reaction. The students conduct the investigation in the classroom or in the laboratory The students present the results of their investigation to the class.
	Design of a Chemical Experiment	Promoting Active Student Participation in the Learning Process.	Materials for Creating the Model.	The teacher presents a scientific problem to the students. The students divide into groups to design an experiment to solve the problem. The students conduct the experiment. The students analyze the results of the experiment.
	Creation of a Chemical Model	Promoting the Understanding	Materials for Creating the Model.	The teacher presents a scientific concept to the students. The students divide into groups to create a model of the scientific concept. The students present their models to the rest of the class.

Note: Own elaboration (2024).

Implementation Phase

This phase was linked to the execution and observation of participant attitudes when initiating, developing, and concluding strategies for teaching natural sciences. In other words, the proposed phases before, during, and after were taken into account. Therefore, understanding how autopoietic systems produce their own conditions of existence involved exploring the mechanisms that allow them to generate and maintain their own internal structures and processes. The main objective of this activity was to expand participants' understanding of the self-organization and self-perpetuation of complex systems, exploring the dynamics that underpin their autonomous existence.

Likewise, recognition was addressed as a fundamental component in knowledge construction, seeking to understand how the act of recognition, both individually and collectively, significantly influences the formation and evolution of knowledge. This activity aimed to explore the connections between perception, recognition, and active construction of understanding in various contexts. Meanwhile, understanding how cognitive structures influence knowledge construction was a relevant focus, as it explored the patterns and cognitive processes underlying the assimilation, interpretation, and application of information, highlighting the importance of cognitive structures in how knowledge is constructed and organized.

Similarly, the notion that knowledge is always contextual and relative was addressed, exploring the elements that contribute to the contextualization of knowledge and recognizing its dynamic nature and its dependence on situational factors. This activity sought to promote awareness of the relativity of knowledge and its intrinsic connection to the environment and particular circumstances. Together, these activities contributed in the past to a deep exploration of cognitive processes, recognition, and self-generation of systems, fostering a more holistic and contextualized understanding of knowledge.

In this regard, concerning the application of strategies in the biology area, specifically with research on a biological phenomenon, the goal was to deepen the understanding of a specific aspect of life, whether at the molecular, cellular, or through more complex biological systems. This activity aimed to discover new knowledge, answer scientific questions, and contribute to the advancement of understanding in the field of biology. Likewise, the design of a biological experiment aimed to apply the scientific method to test hypotheses and validate theories. Through careful planning of variables and controlled conditions, significant data supporting or refuting the hypothesis was intended to be obtained. This process not only contributed to scientific research but also developed skills in experimental design and critical analysis.

Therefore, the creation of activities in the biology subject involved the conceptual or physical representation of a specific biological system. It was used to simulate biological processes, understand relationships between different components, or predict behavior under specific conditions. Through the activities, the aim was to provide a tool that facilitated the understanding and study of biological phenomena in a more accessible and visual way. These activities were implemented over the course of a month.

Regarding activities in the physics area, researching the reconstruction of a physics experiment aimed to deepen understanding of specific physical phenomena by recreating and analyzing previous experiments. This activity's main objective was to obtain a more detailed understanding of the physical principles involved, as well as to improve the research and analysis skills of the participants. The design of a scientific project involved formulating and executing a structured plan to investigate and address specific scientific questions. This activity aimed to foster creativity and the practical application of scientific knowledge, promoting the development of skills in experimental design, data analysis, and clear and coherent presentation of results. It's worth noting that these activities were worked on consecutively over the course of a month.

Additionally, participation in a science fair represented an opportunity to communicate and share the results of research and scientific projects with a wider audience. This event not only aimed to highlight individual achievements but also to encourage interaction and exchange of ideas among participants and the scientific community at large, promoting interest and appreciation for science. Together, these activities sought to cultivate scientific thinking, independent research, and the ability to effectively communicate scientific findings.

In relation to the chemistry area, the activities were implemented over the course of one month. Regarding the topic of chemical reactions, the aim was to deepen understanding of specific chemical processes through analysis and detailed exploration of these reactions. This activity's main objective was to expand participants' knowledge about the principles and mechanisms governing chemical reactions, thus promoting a deeper understanding of the world of chemistry. Likewise, in the design of a chemical experiment, in the past, a structured plan was formulated and executed to investigate and explore specific scientific questions related to chemical reactions. This activity aimed to foster creativity and the practical application of chemical knowledge, developing skills in experimental design, data analysis, and precise and coherent presentation of results.

Finally, the creation of a chemical model in the past involved the conceptual or physical representation of a specific chemical system. This model was used to simulate chemical processes, understand relationships between different components, and predict behavior under specific conditions. The activity aimed to provide a tool that facilitated the understanding and study of chemical phenomena in a more accessible and visual way. Together, these activities contributed to cultivating scientific thinking, independent research, and the ability to apply and effectively communicate the knowledge acquired in the chemical field.

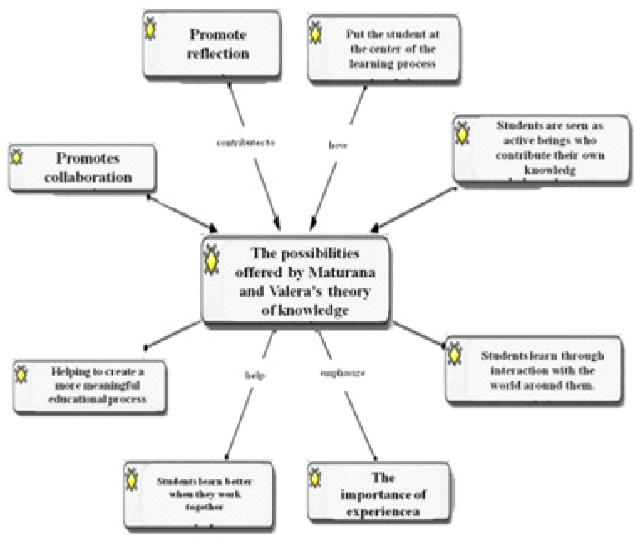
Evaluation Phase

This phase allowed the researcher to interpret, explain, and draw conclusions from the activities carried out. This evaluation was conducted to analyze the possibilities offered by Maturana and Varela's theory of knowledge for the development of educational methodologies in natural science teaching. After applying each phase and especially fulfilling the planning of activities in the areas of biology, physics, and chemistry, new teaching criteria based on student progress were established. Therefore, after implementing the action plan, teachers were evaluated through interviews, while students underwent a written and oral exam, which was analyzed to extract areas for improvement.

Results

The following are the emerging categories from the interviews conducted with teachers, which were interpreted in a general manner by the researcher.

Figure 1
Possibilities offered by the theory of knowledge of Maturana and Varela



Note: Semantic network Atlas Ti. Own elaboration (2024)

In Figure 1, the categories that emerged from the discourse of the interviewed teachers are shown, demonstrating that, according to them, the methodology based on Maturana and Varela's theory of knowledge benefited the educational process in various ways. Primarily, because *it places the student at the center of the learning process*. According to the natural science teachers who participated in the implementation of the action plan, placing the student at the epicenter of the educational process, in accordance with Maturana and Varela's Theory of Knowledge, implies a transformative pedagogical approach. It was observed during the activities that the students participated in the construction of their own knowledge, moving away from traditional teacher-centered approaches.

They also expressed that these activities allowed them to appreciate the innate ability of students to learn and adapt to their environment. This is because the teaching process was presented to them as a dynamic and bidirectional experience, where the student not only absorbed information but also interacted, questioned, and constructed meanings from their experiences. At the same time, the activities worked with the self-regulation and autonomy of fifth-year students, which was decisive, as this allowed them to explore, experiment, and reflect on scientific concepts actively.

Additionally, through the activities carried out, contextualized learning was evident, where the content was linked to the students' reality and experiences. This connection with their immediate environment and daily experiences facilitated a deeper and more meaningful understanding of the topics addressed. Furthermore, interdisciplinary learning was promoted, allowing students to explore natural sciences from various perspectives and disciplines, enriching their overall understanding.

On the other hand, the teachers stated that students had a different perception of natural sciences since, by contrasting the traditional view of learning, where the teacher was seen as the provider of knowledge and the students as passive recipients of said knowledge, students themselves guided the topics of study through their participation.

All this was because, through the execution of the planned activities, students *were seen as active participants in the construction of their knowledge*. This indicates that the methodology based on Maturana and Varela's theory of knowledge emphasizes the importance of experience, *as each student participated by interacting with the world around* them, namely, with their own reality, highlighting the importance of students having opportunities to experience the world firsthand. This was done through practical activities, i.e., through experiments, projects, and field visits.

Furthermore, according to natural science teachers, *the experience gained fundamental importance* in the context of teaching biology, chemistry, and physics from Maturana and Varela's Theory of Knowledge. They began this statement by highlighting that the activities allowed for a deep understanding that learning is not an isolated process from reality but an active construction nourished by the experiences lived by the student. Additionally, they emphasized that the experience provided the meaningful context necessary for scientific concepts to gain relevance and meaning. By integrating theory with practice, students not only memorized information but also understood it through its application in real situations. This contributed to the formation of a more ingrained and applicable knowledge in everyday life.

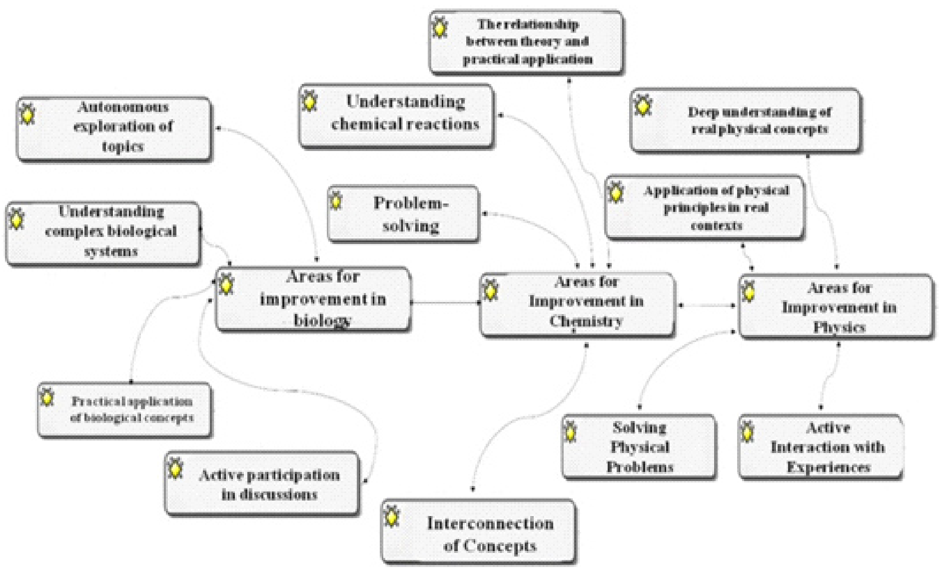
Moreover, the teachers expressed that the methodology based on Maturana and Varela's theory of knowledge promotes collaboration, *as students learn to work together*. It was observed that teamwork to solve problems and share ideas helped them provide solutions. Collaboration helped them develop critical thinking skills, problem-solving, and teamwork skills. Hence, the importance of *promoting collaboration* so that the experiences and ideas of some benefit others.

Within this framework, they also stated that methodologies based on Maturana and Varela's Theory of Knowledge foster curiosity and promote the integration of positive emotional experiences, thus activating more effective cognitive processes. Additionally, they stimulated collaborative learning, in line with the social perspective of the theory, enriching the exchange of ideas and perspectives, contributing to a more holistic and enduring understanding of natural sciences. This methodology allowed observing that students need time to *reflect on their learning* and how it relates to their own experience. Reflection helps them better understand the knowledge they are constructing.

Now, when evaluating students in each subject (biology, chemistry, and physics), several categories related to the study objectives were extracted, which were disaggregated into the parts of each written and oral assessment:

Figure 2

Areas of improvement in the subjects of physics, chemistry, and biology



Note: Semantic network Atlas Ti. Own elaboration (2024)

Figure 2 shows the results of evaluations applied to 5th-year students during the implementation of biology activities. In this regard, students demonstrated *outstanding commitment to active participation in discussions*, as observed through oral exams, where they made efforts to be dynamic elements in the exchange of ideas. They notably showed a disposition to ask reflective questions, provide critical analysis, and foster enriching dialogue that benefited the entire group.

Regarding the *practical application of biological concepts*, this category stands out because students immersed themselves in activities and experiments that tested their theoretical knowledge. This experience allowed them not only to understand the concepts superficially but also to integrate them into concrete situations, thereby strengthening their understanding and practical skills in the biological field.

In terms of *understanding complex biological systems*, the activities led students to unravel the intricate connections between the various elements that make up these systems. It was observed that they dedicated time to studying these interrelationships in detail and analyzing how they affect overall functioning. This meticulous approach allowed them to acquire a deeper and more holistic perspective of complex biological systems.

Another underlying category in the field of biology was the exploration of *understanding complex biological systems*, where students demonstrated a proactive attitude towards continuous learning. Their efforts to constantly seek new sources, participate in related extracurricular activities, and willingness to tackle advanced topics evidenced their commitment to expanding their knowledge in the field of biology, as well as their readiness to explore the complexities this field presents when linked to their daily lives.

When analyzing the evaluations in the area of chemistry, the following categories emerged: *problem-solving*, where students were observed to put significant efforts into developing their analytical and problem-solving skills. They also actively participated in practical exercises, showing that each activity represented a challenge for them to address complex problems and effectively apply the chemical principles learned to find precise and logical solutions.

Regarding the *understanding of chemical reactions*, which was another category extracted, it was observed that students made efforts to go beyond superficial memorization. They worked on understanding the intrinsic dynamics of reactions, identifying the factors that influence them, and applying this knowledge to predict results and explain phenomena observed in the laboratory.

Additionally, the *category of theory-application relationship emerged*, where it was evident that students sought to coherently integrate theoretical concepts with practical experiences in the laboratory. This demonstrated that their objective was not only to understand the theories behind chemical processes but also to effectively apply them in practical settings, thus strengthening their comprehensive understanding of the subject matter or topics covered.

Another category extracted was *the interconnection of concepts*, where it was observed that students worked to visualize how different chemical ideas and theories intertwine. At the same time, it was evident that they explored the relationships between various concepts, recognizing the importance of understanding how a chemical principle can influence others and how these connections contribute to a deeper and more global understanding of the discipline (chemistry).

When analyzing the physics subject, progress was evident regarding problem-solving in physics, with students showing greater effort and desire to develop their skills in addressing complex situations and deriving solutions using physical principles. As a demonstration of this, they actively participated in solving practical problems, feeling challenged by exercises requiring an analytical approach and the precise application of physical formulas and theories.

In this regard, *the application of physical principles in real contexts was presented*, where they sought opportunities to bring theoretical concepts into the tangible world. To achieve this, they engaged in each proposed activity and practical situations requiring the direct application of physical principles in solving real-world problems, thereby strengthening their ability to link theory with concrete applications.

Regarding the *deep understanding of real physical concepts*, it was observed that they dedicated time to explore beyond the surface of basic theories. They expressed a focus on understanding fundamental and often complex physical theories at a deeper level, recognizing the broader implications and connections these theories have in the overall landscape of physics.

Finally, through *active interaction with experiments*, they sought to directly engage in the practical application of physical concepts by carrying out each proposed activity in this area (physics). Thus, it was observed that their active participation in experimental activities not only demonstrated their effort in theoretical understanding but also improved their ability to relate experimental results to the underlying physical principles, enriching their experience in the field of physics.

Discussion

When contrasting the study results with various theories, including those of Rodríguez & Torres (2003), it becomes evident that placing the student at the center of the learning process is crucial. This perspective reflects a paradigm shift towards more meaningful and autonomous learning, where students not only absorb data but also actively participate in exploring and understanding concepts.

Additionally, according to Ball *et al.* (2014) and Hernández (2009), the active participation of students in constructing their knowledge underscores the importance of involving them directly in the educational process. By assuming active roles, students not only memorize information but also develop critical skills in analyzing and applying knowledge, thereby enhancing their ability to understand and recall concepts more effectively.

In this regard, Ruiz (2008) highlights that the direct interaction of each student with the surrounding world in the learning process is fundamental for contextualizing information and giving it relevance. Maturana & Maturana (2003) indicate that this approach allows students to apply theories and concepts in practical situations, creating tangible connections between theory and reality. Practical experience enriches learning by providing a deeper and more meaningful understanding of concepts, emphasizing the importance of learning through action.

According to Maturana & Dávila (2006), collaboration and teamwork among students are fundamentally important as they reflect the reality of the work and social environment. Learning to work as a team not only develops social and communication skills but also broadens individual perspectives by integrating diverse experiences and approaches. This collaboration is valuable not only in the academic sphere but also prepares students for future interactions in the real world, as stated by Gorostiza (2021).

Bedoya (2023) emphasizes that activating more effective cognitive processes highlights the importance of stimulating students' critical and analytical thinking. By promoting problem-solving, logical reasoning, and the practical application of knowledge, deeper and more lasting learning is promoted. This cognitive activation not only improves information retention but also strengthens students' ability to tackle complex challenges.

Thus, Jové (2022) argues that reflection on learning is fundamental to the teaching of natural sciences, as it fosters metacognition and individual awareness of the learning process. According to Maturana (2004), by encouraging students to reflect on how they approach and understand concepts, a deeper understanding is promoted, along with the ability to apply more effective learning strategies. Therefore, reflection also facilitates the identification of areas for improvement and the development of self-regulation skills, thus contributing to more autonomous and meaningful learning.

Conclusions

The study concludes that, from the perspective of Maturana and Varela's Theory of Knowledge, educational methodologies show fundamental improvements in teaching, which involves promoting active experimentation. Educators can design activities that engage students in conducting experiments and practical projects, allowing them to interact directly with concepts. This approach not only enhances theoretical understanding but also empowers students by enabling them to discover and explore physical phenomena themselves, thus fostering their autonomy in the learning process.

Furthermore, in the field of chemistry, significant improvements can be achieved by focusing on the practical application of chemical principles. That is, integrating methodologies that highlight the application of chemical theories in solving real-world problems is relevant because, by encouraging projects that require the practical application of these principles, the connection between theory and application is strengthened, promoting a deeper and more meaningful understanding of chemistry. This approach aligns teaching with Maturana and Varela's idea that knowledge is actively constructed through action and experience.

Similarly, in the context of biology, there are significant improvements, as students can focus on the interconnection of biological concepts. Educators can design activities that highlight the interrelationships between various biological concepts and complex systems. Therefore, methodologies aligned with Maturana and Varela's vision of active knowledge construction promote a holistic and contextualized understanding of the natural sciences. This is because they encourage the exploration of the complex relationships between different biological, physical, and chemical aspects, enabling students to develop a deeper and more interconnected understanding of each discipline.

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